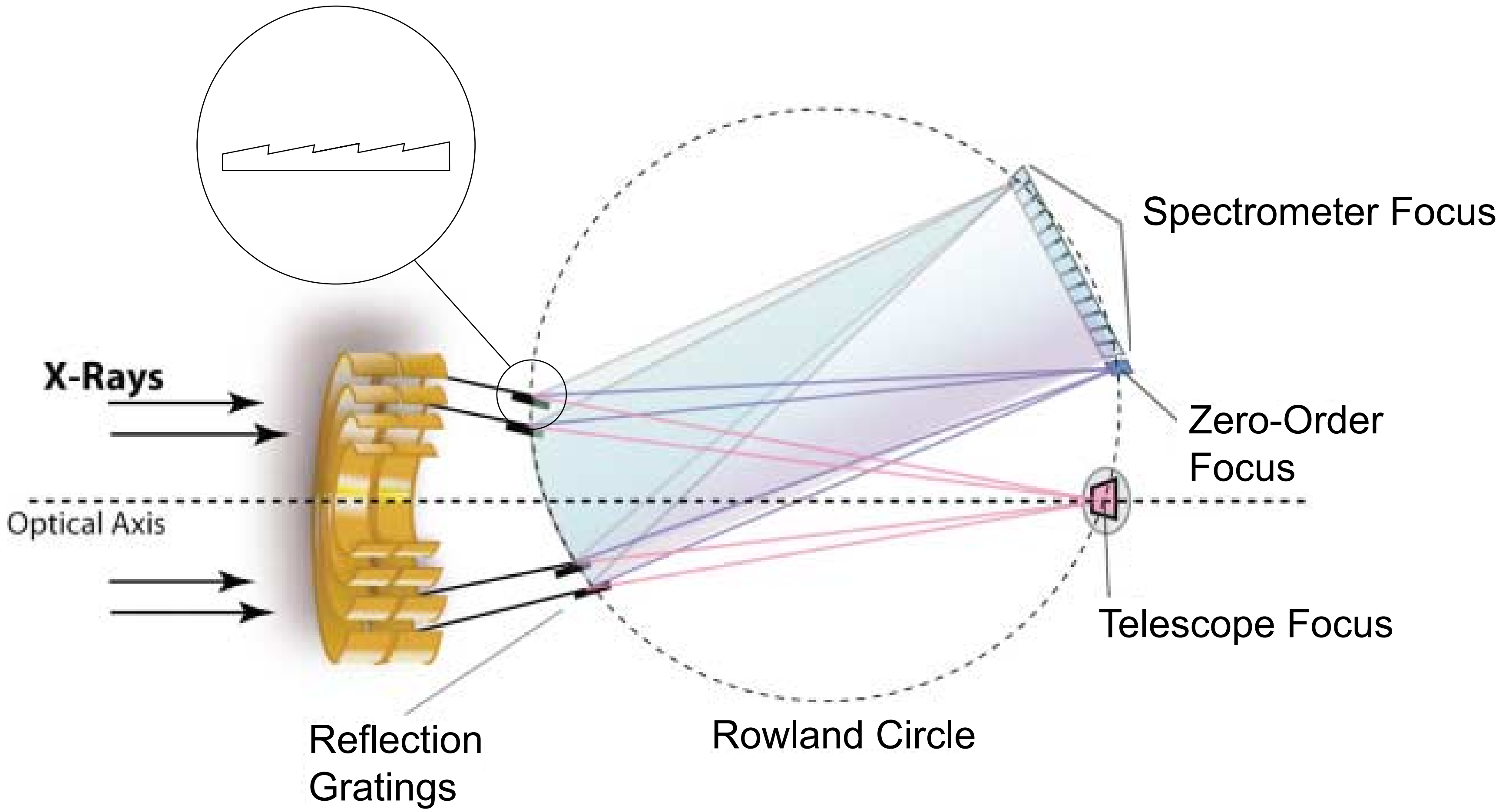
Reflection Grating Development Update

Ralf K. Heilmann, Mireille Akilian, Chih-Hao Chang,
Craig R. Forest, Chulmin Joo, Juan C. Montoya,
Amir Torkaman, and Mark L. Schattenburg

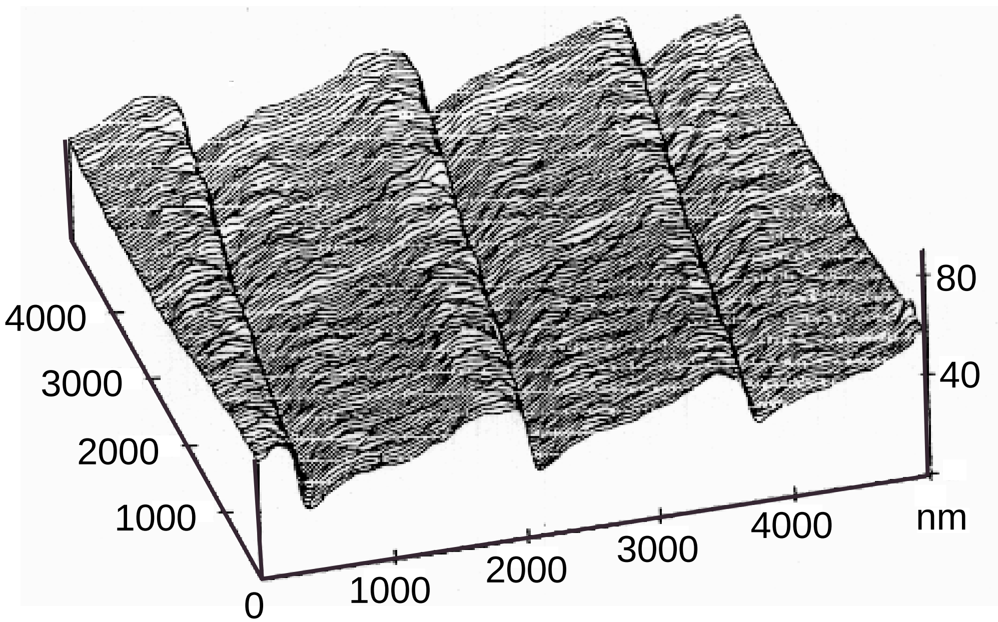
Space Nanotechnology Laboratory, Center for Space Research
Massachusetts Institute of Technology, Cambridge, MA

Constellation-X Facility Science Team Meeting
GSFC, Nov. 19-20, 2003

Constellation-X Telescope and Reflection Grating Geometry

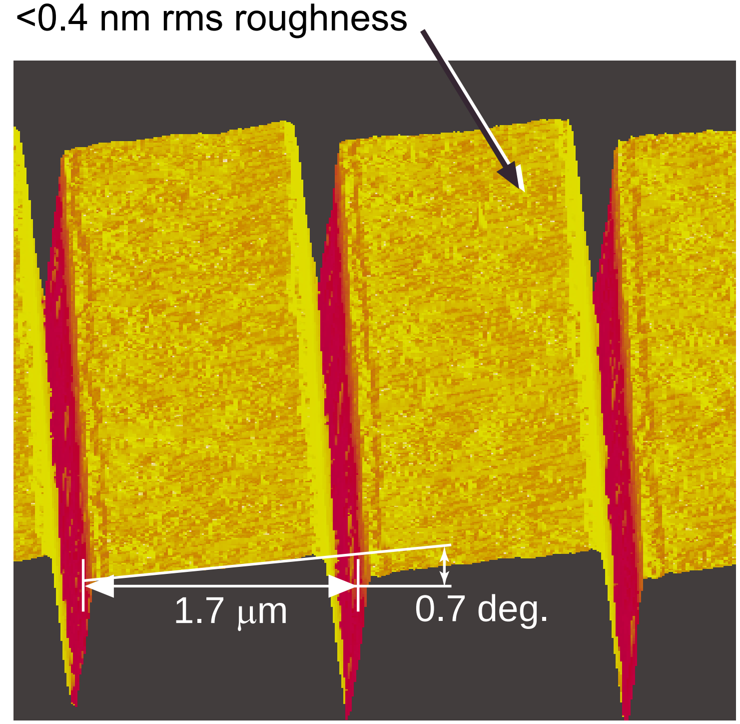


Super Smooth Reflection Grating Fabrication Results - **In-Plane**



Mechanically Ruled and Replicated
(XMM Grating - Old Technology)

Si (111) planes,
<0.4 nm rms roughness



Anisotropically Etched
(MIT Grating - New Technology)

In-Plane (shown above): period = 1.7 μm, blaze angle = 0.7 deg
Off-Plane: period = 0.2 μm, blaze angle ~ 7 deg

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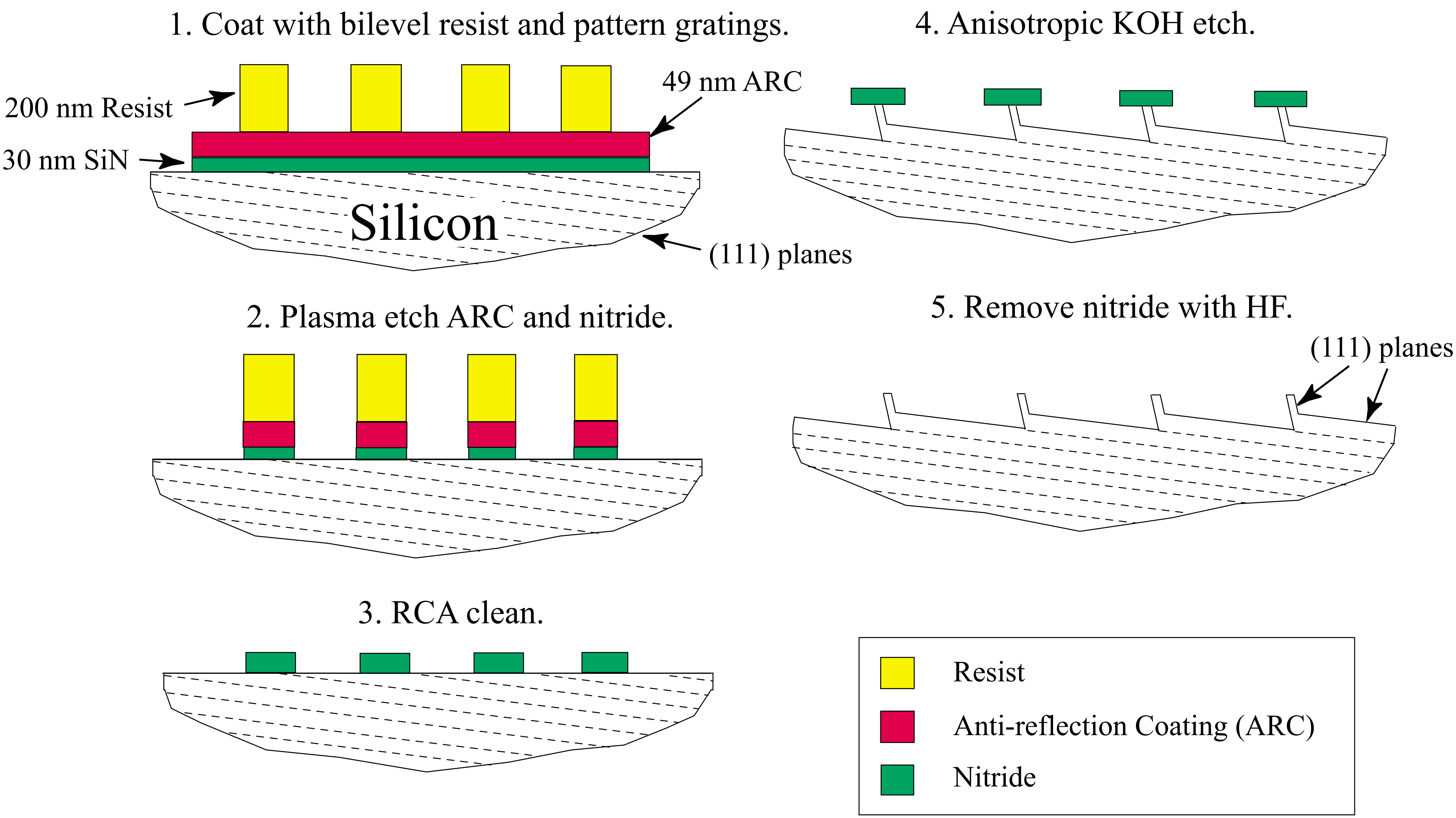
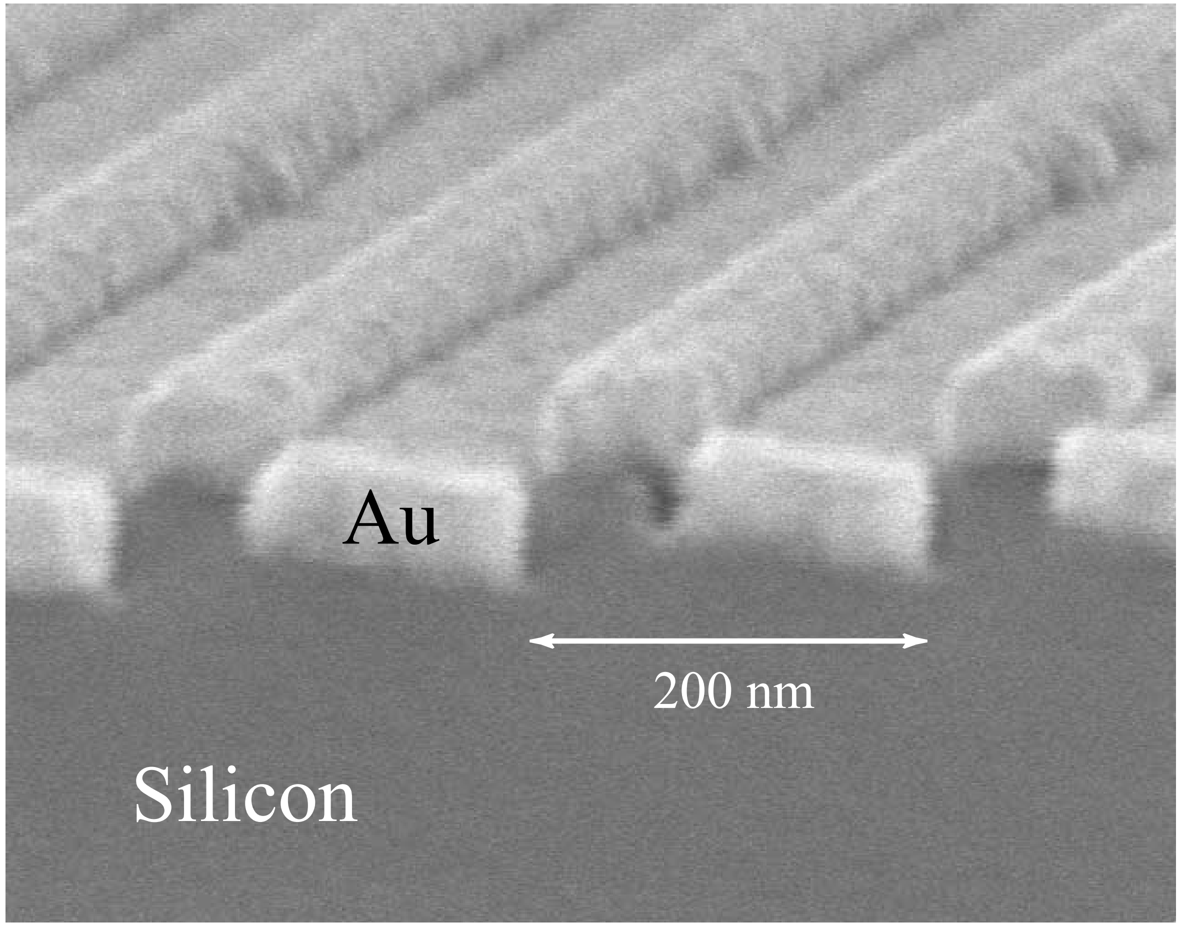
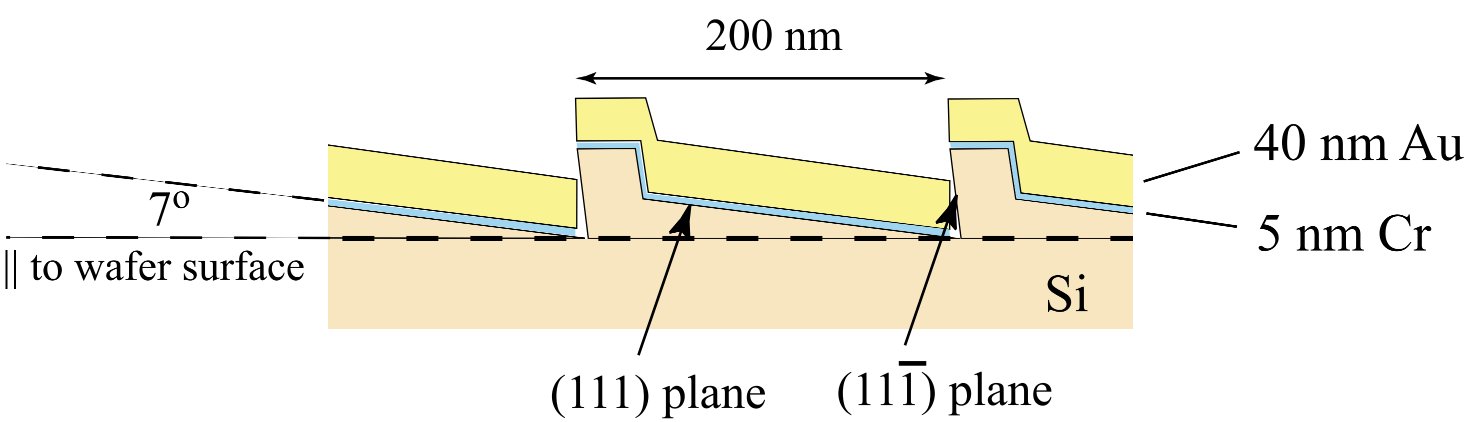
Super-Smooth Blazed Reflection Gratings From Miscut Silicon



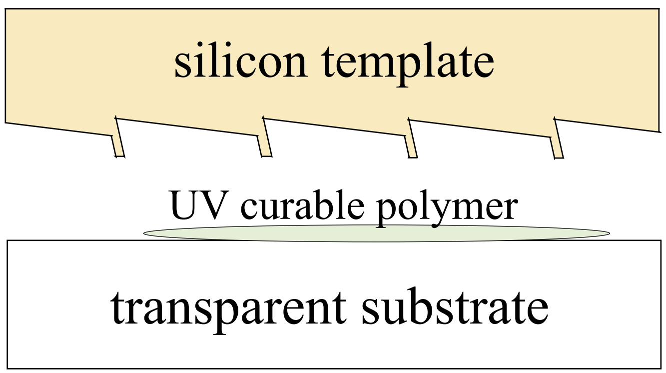
SEM of Blazed Cr/Au-Coated Off-Plane Grating



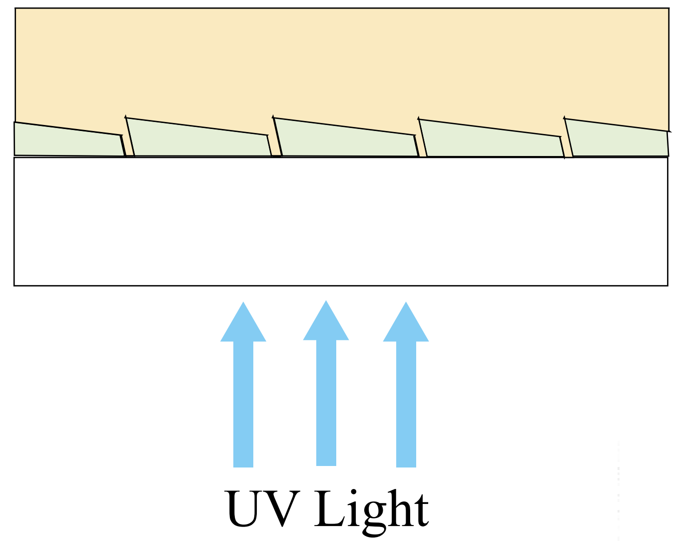


Grating Replication with Nanoimprint Lithography

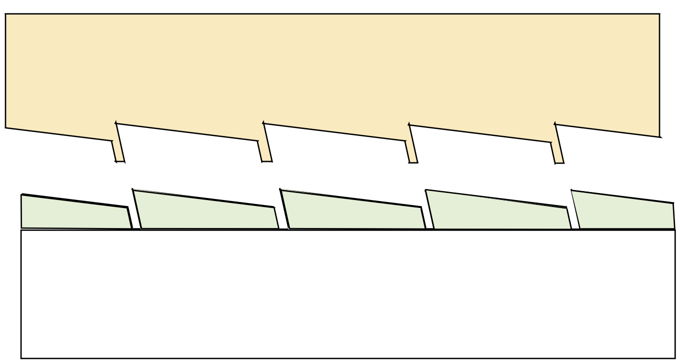
1. Add polymer to the surface

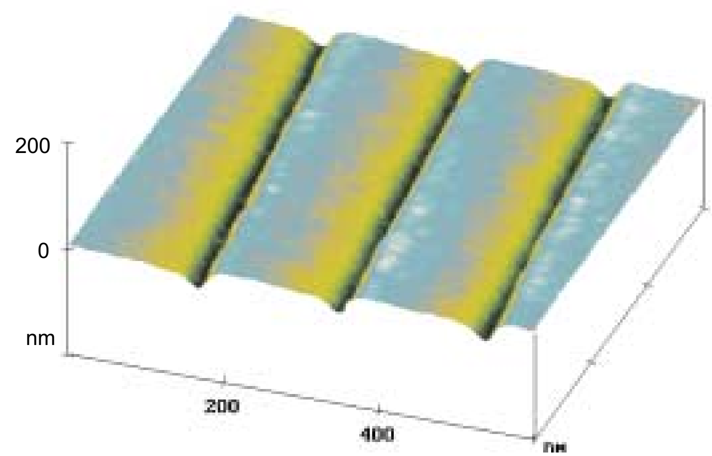


2. Close the gap, cure polymer with UV light



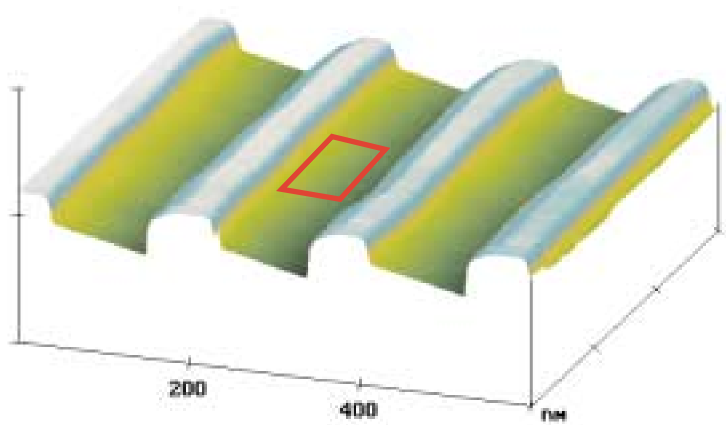
3. Remove mold





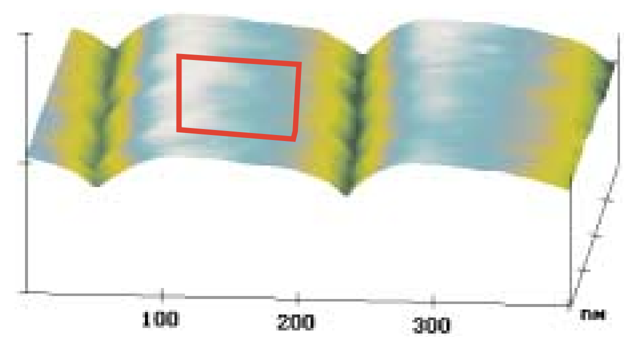
Atomic Force Microscopy (AFM) Results: Microroughness

silicon mandrel



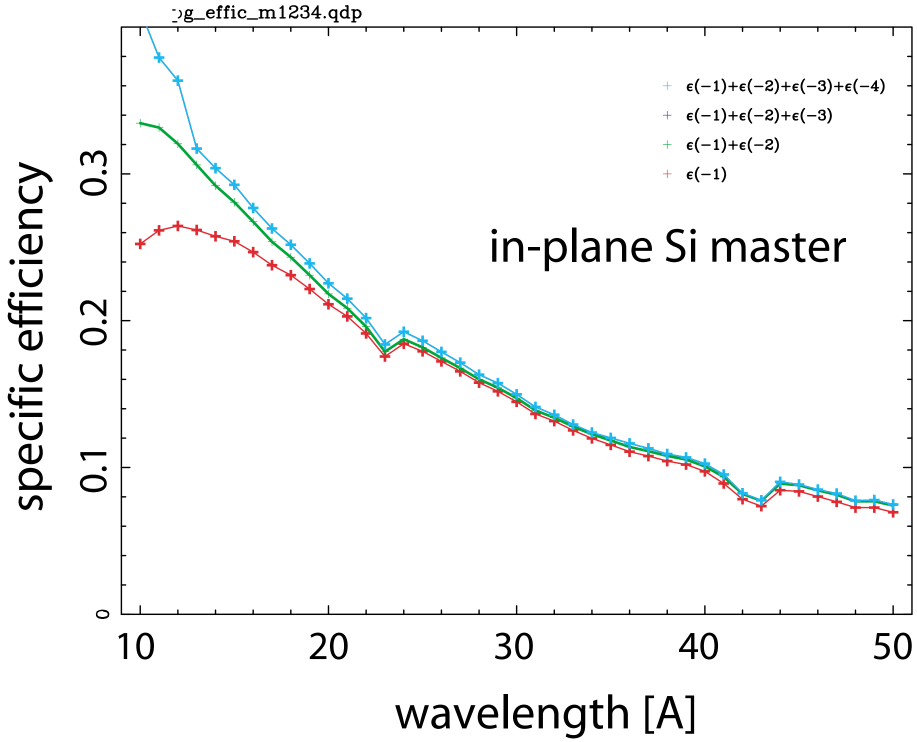
σ = 0.15 nm

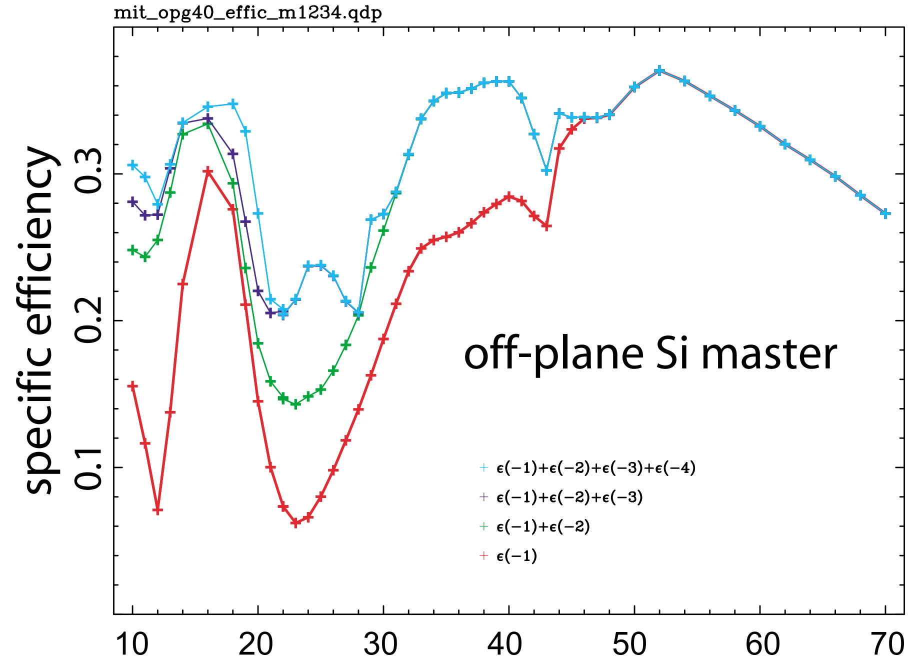
NIL replica



σ = 0.16 nm
(0.17 nm with Au coating)

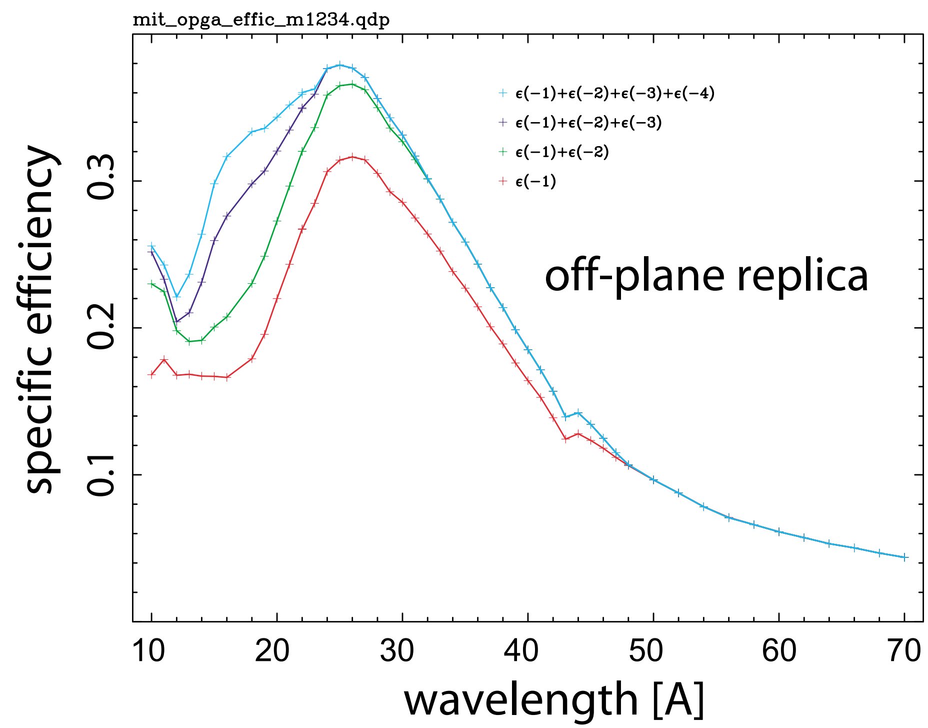
COMPARISON OF DIFFRACTED ORDER EFFICIENCIES (1,1+2,1+2+3,1+2+3+4)



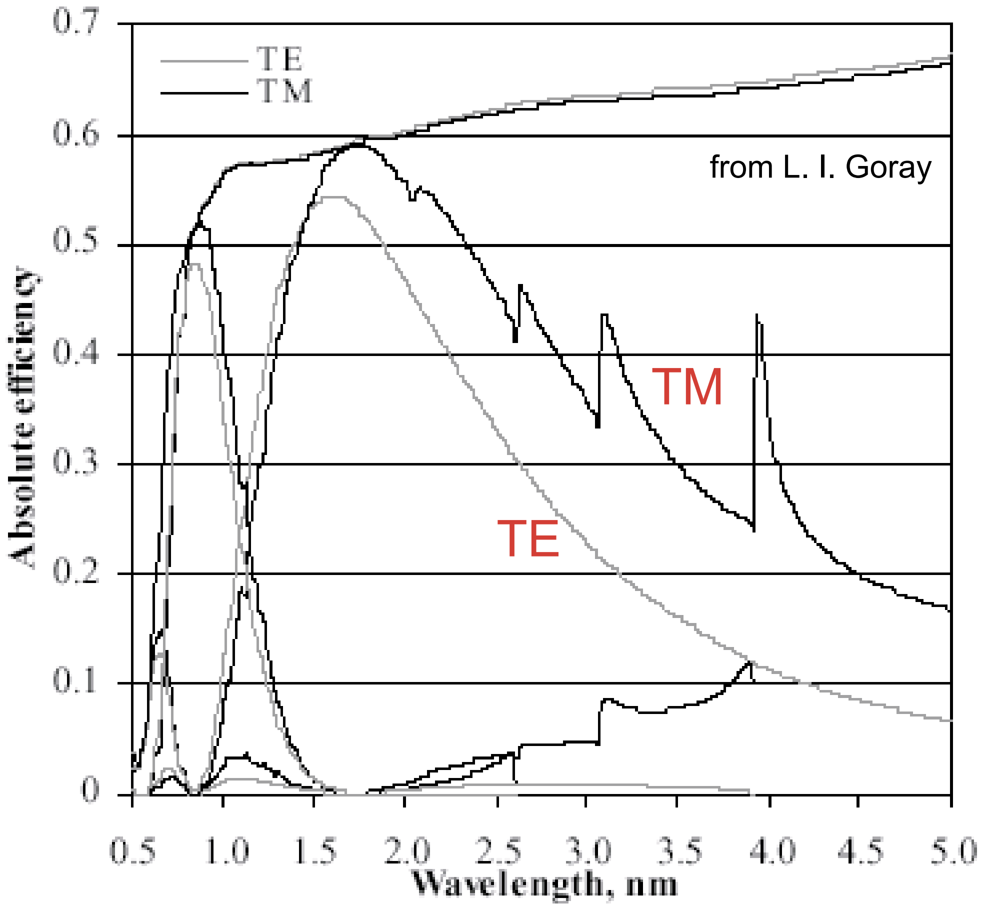


Diffraction Efficiency Measurements

(Advanced Light Source, LBL, A. Rasmussen *et al.*)



Simulations predict off-plane polarization sensitivity



Absolute efficiency in the –1, –2, and –3 orders of a 5000- gr/mm triangular grating with 7° working facet angle and 5 A rms roughness (off-plane geometry)

Current synchrotron data:

TE polarization (lower efficiency)

Future studies:

Measure efficiency in TE and TM polarization

(NRL beamline at NSLS)

From: L. I. Goray, "Rigorous efficiency calculations for blazed gratings working in in- and off-plane mountings in the 5–50-Å wavelengths range," Proc. SPIE 5168

Grating Replication: Why Nanoimprint Lithography?

Goals:

grating substrate bow < 0.25 ∝m
roughness < 0.5 nm
feature size < 100 nm

Traditional epoxy replication:

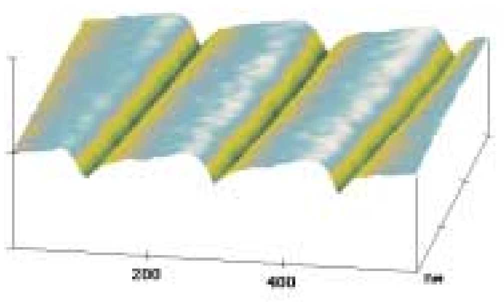
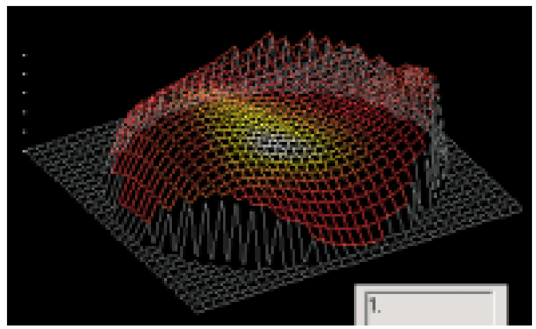
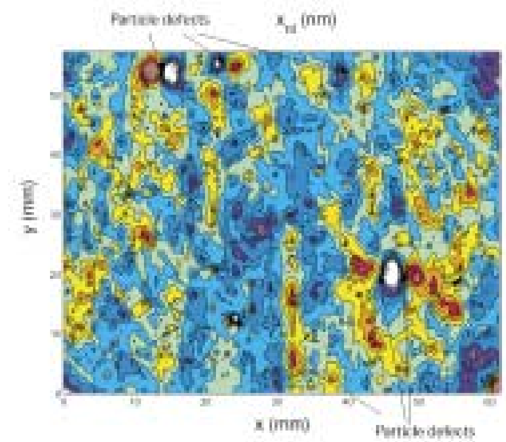
- 10 - 40 ∝m thick films
- 1 - 2 ∝m thickness variation
- thin films stress (shrinkage)
- outgassing
- feature fidelity?
- roughness?

Nanoimprint Lithography:

- films < 0.1 ∝m thin
- thickness variation << film thickness
- reduced bowing from thin films stress
- reduced outgassing
- excellent feature fidelity (< 10 nm)
- roughness < 0.5 nm

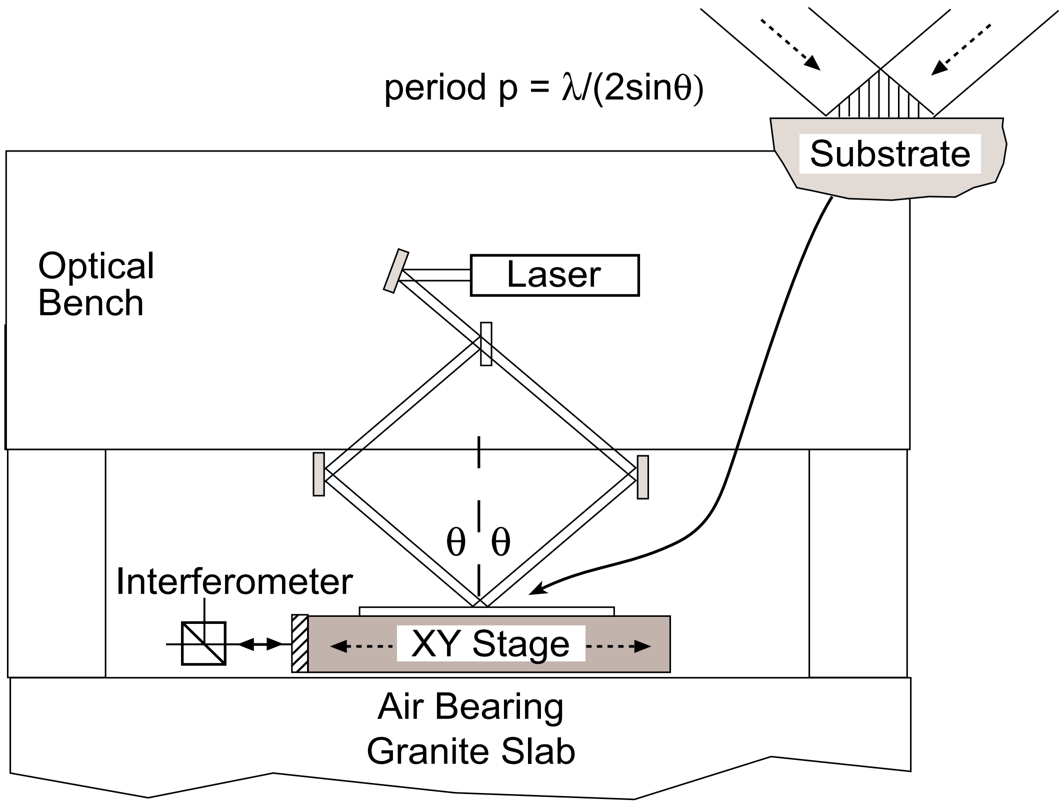
Nanoimprint Lithography Study

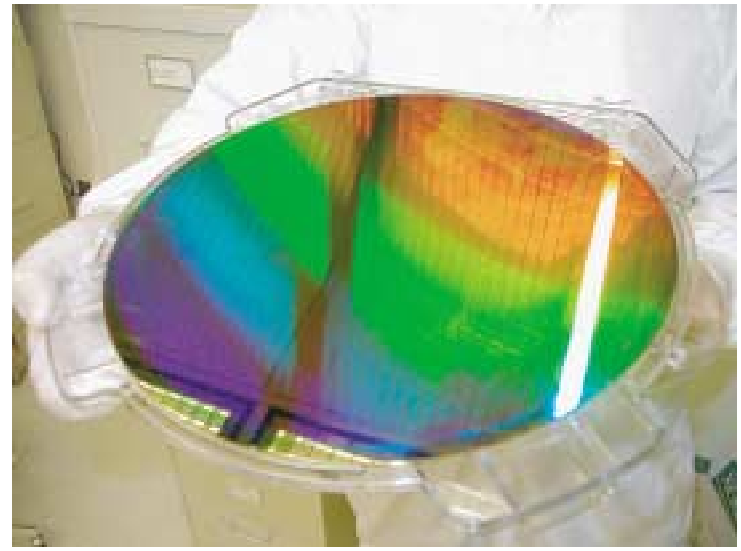
- Produce and characterize grating mandrels

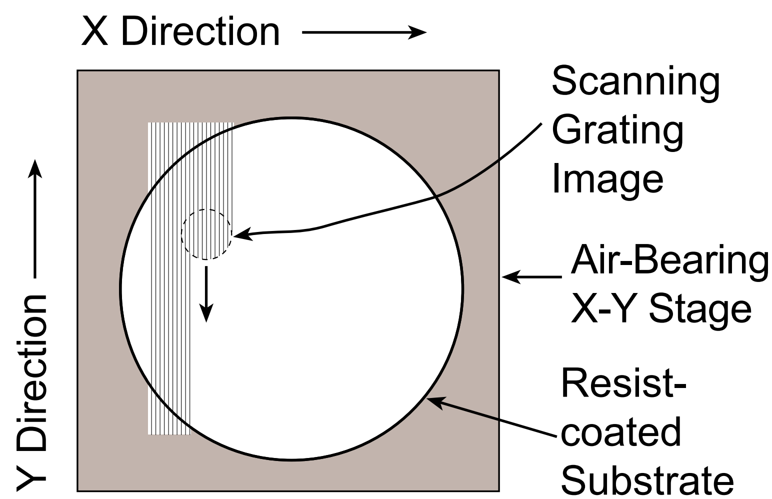
AFM	Shack-Hartmann	Nanoruler
		
groove profile microroughness	substrate figure flatness out-of-plane distortions	grating phase map particle defects in-plane distortions

- NIL vendors fabricate replicas
- We characterize replicas (AFM, SH, Nanoruler)
- First samples are being replicated

Scanning Beam Interference Lithography with the Nanoruler (fixed period)







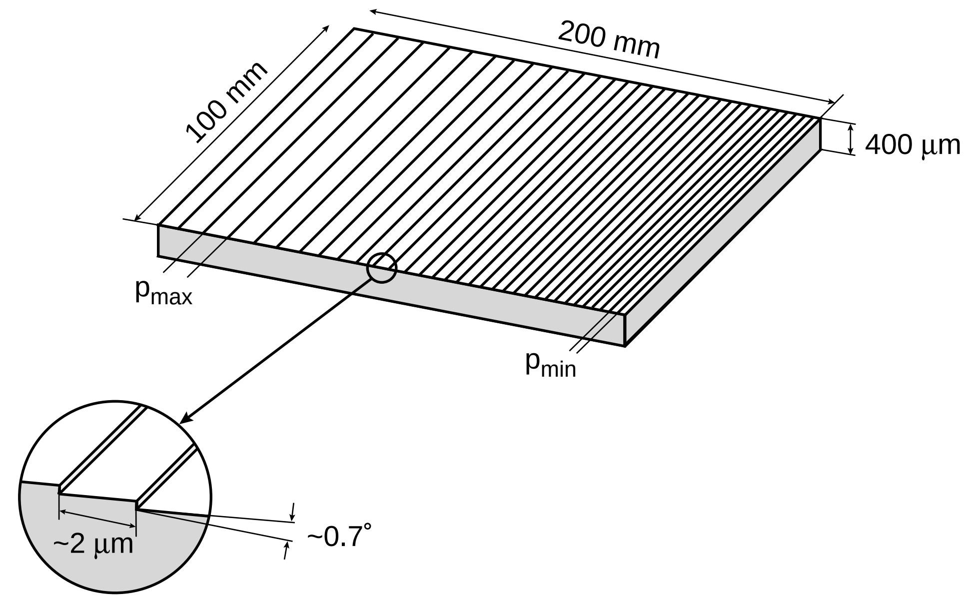
Patterning gratings with Variable-Period Scanning Beam Interference Lithography (VP-SBIL)

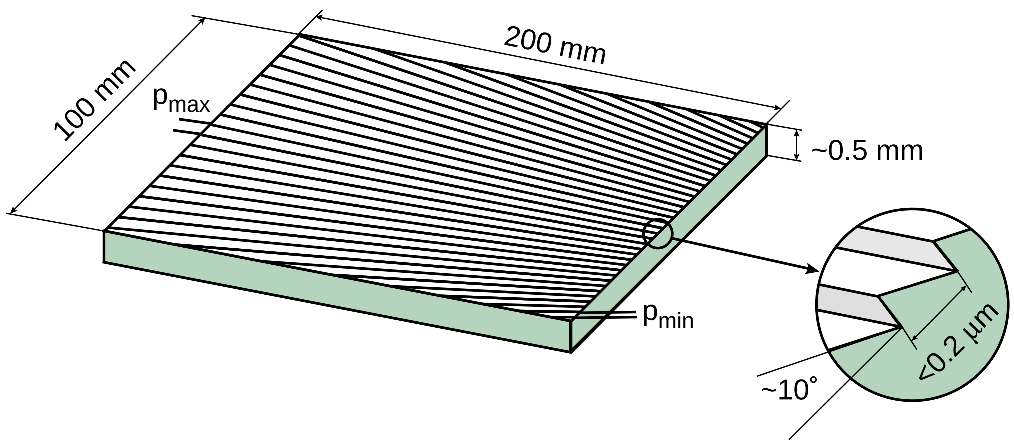
In-plane geometry: chirped grating

p_{ave} ~2 μm

Chirp Δp/p ~5%

Blaze ~0.7˚





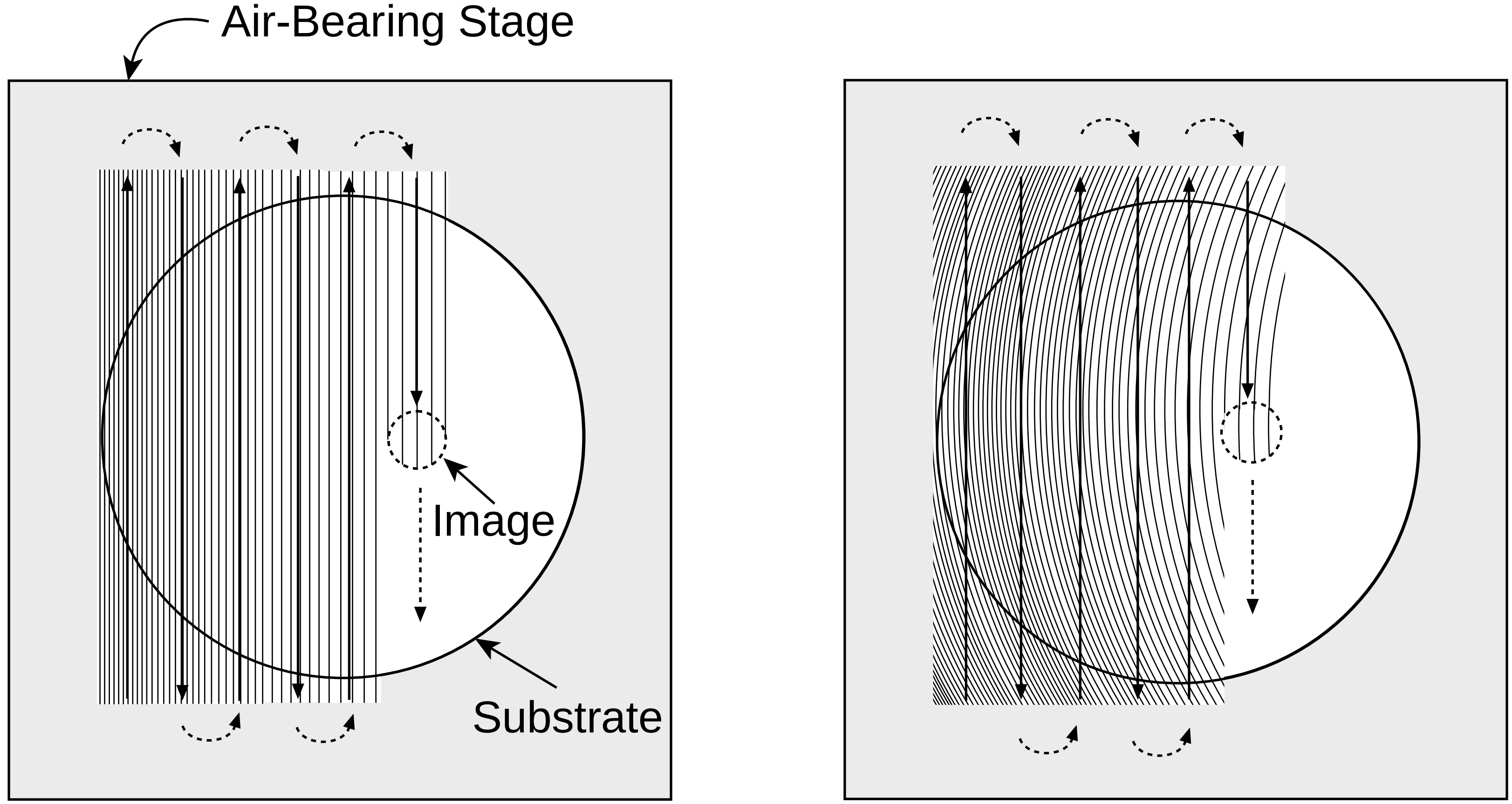
Off-plane geometry: radial grating

p_{ave} <0.2 μm

Chirp Δp/p ~2%

Blaze ~10˚

Writing General Periodic Patterns with SBIL



(a) Linear Chirped Grating

(b) Curved Chirped Grating

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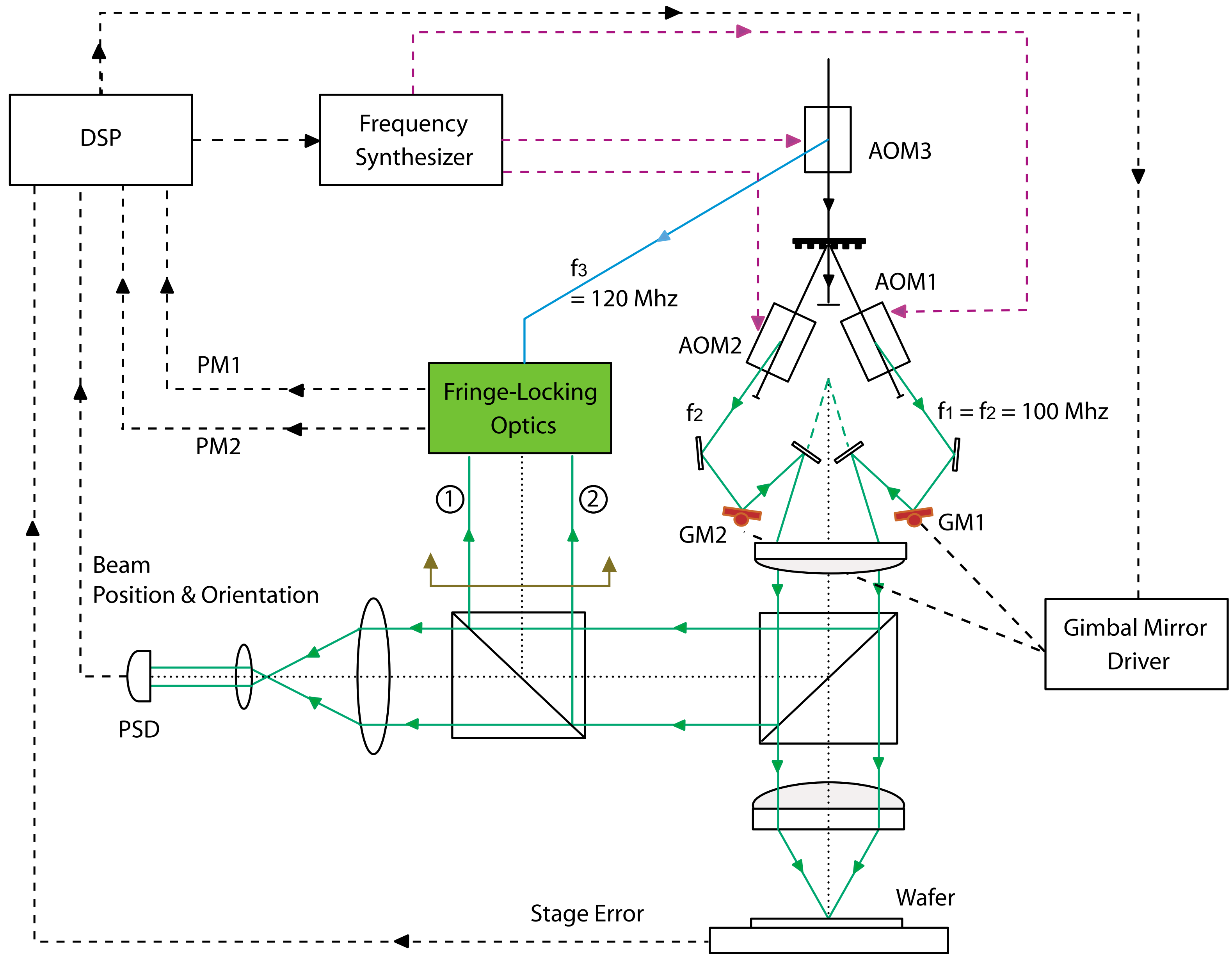
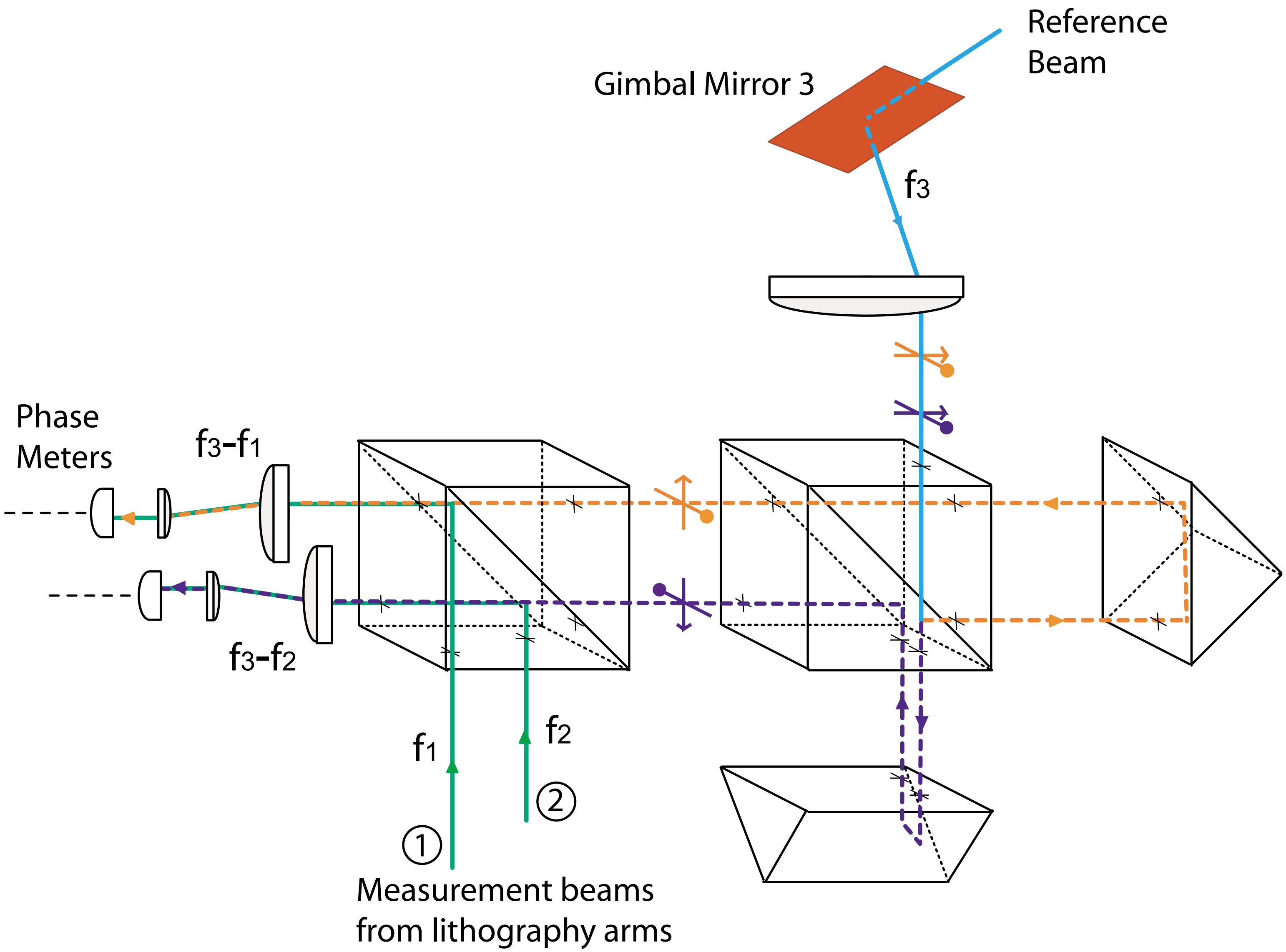
Variable Period - SBIL Concept



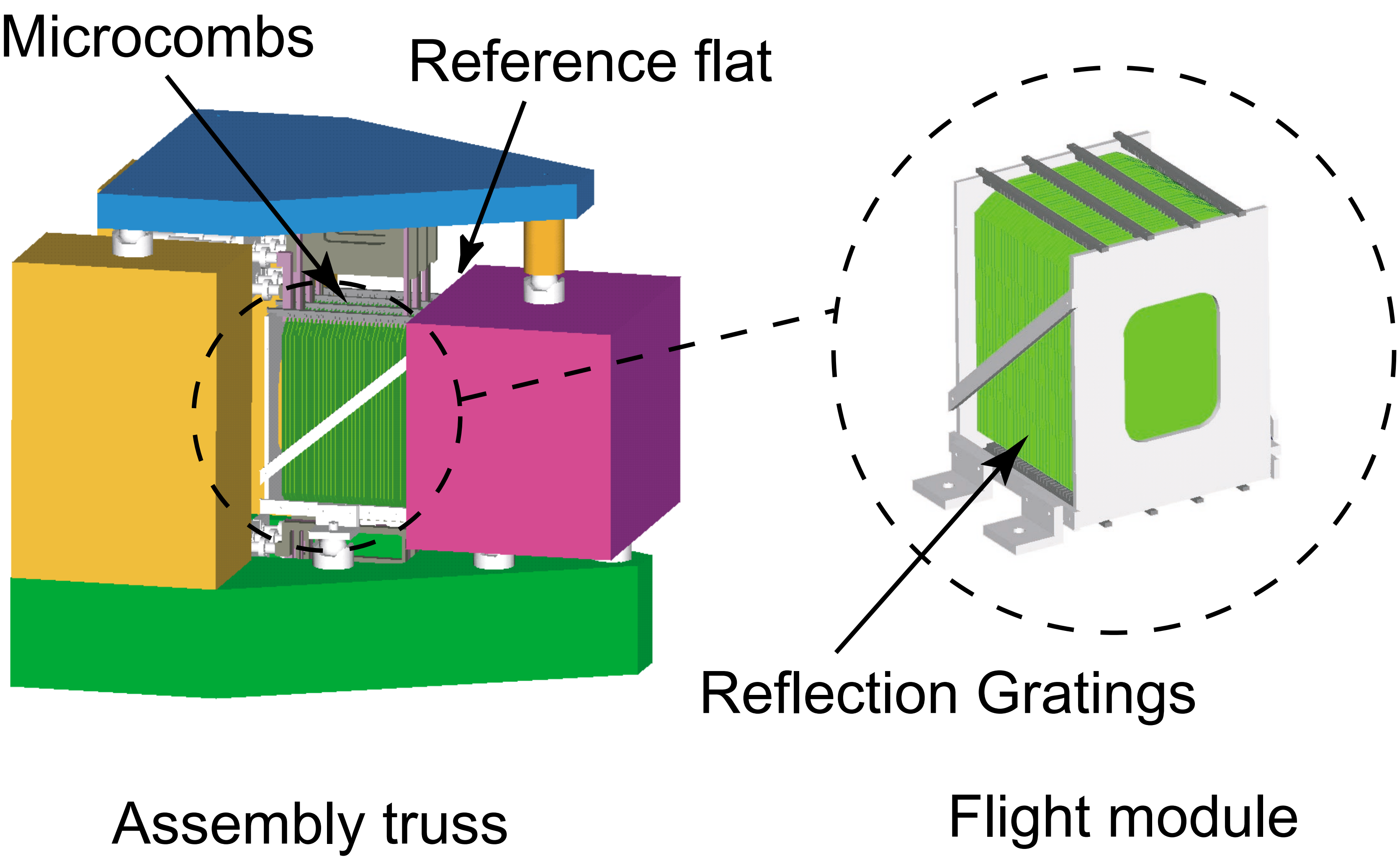
cj-vpsbil.eps

VP-SBIL detail: Heterodyne fringe locking system

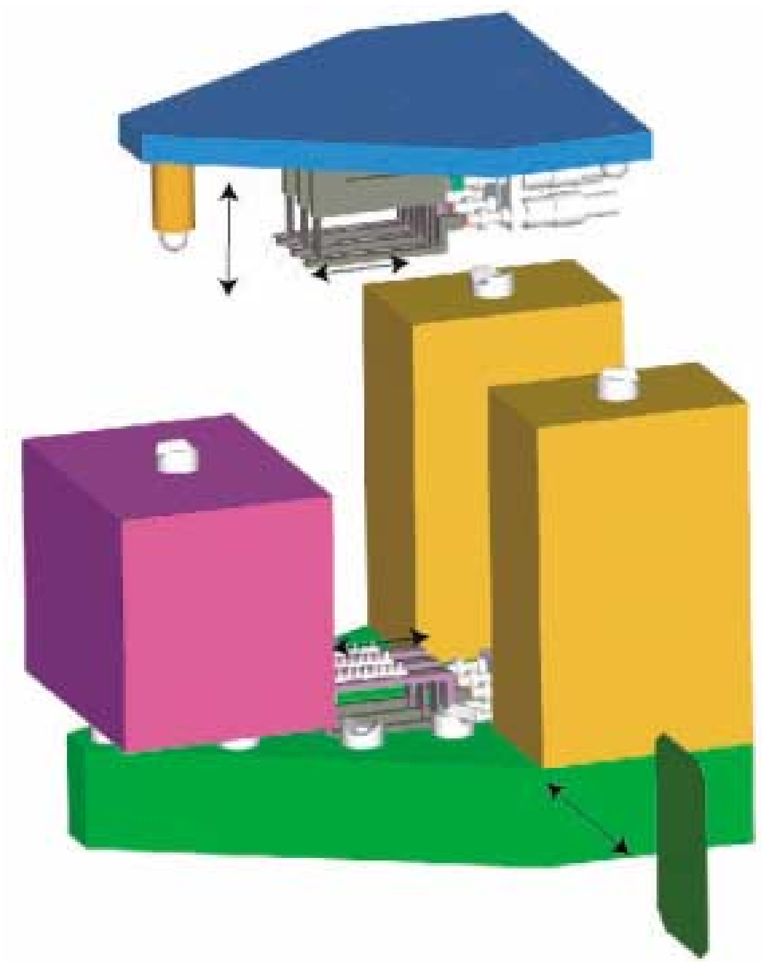


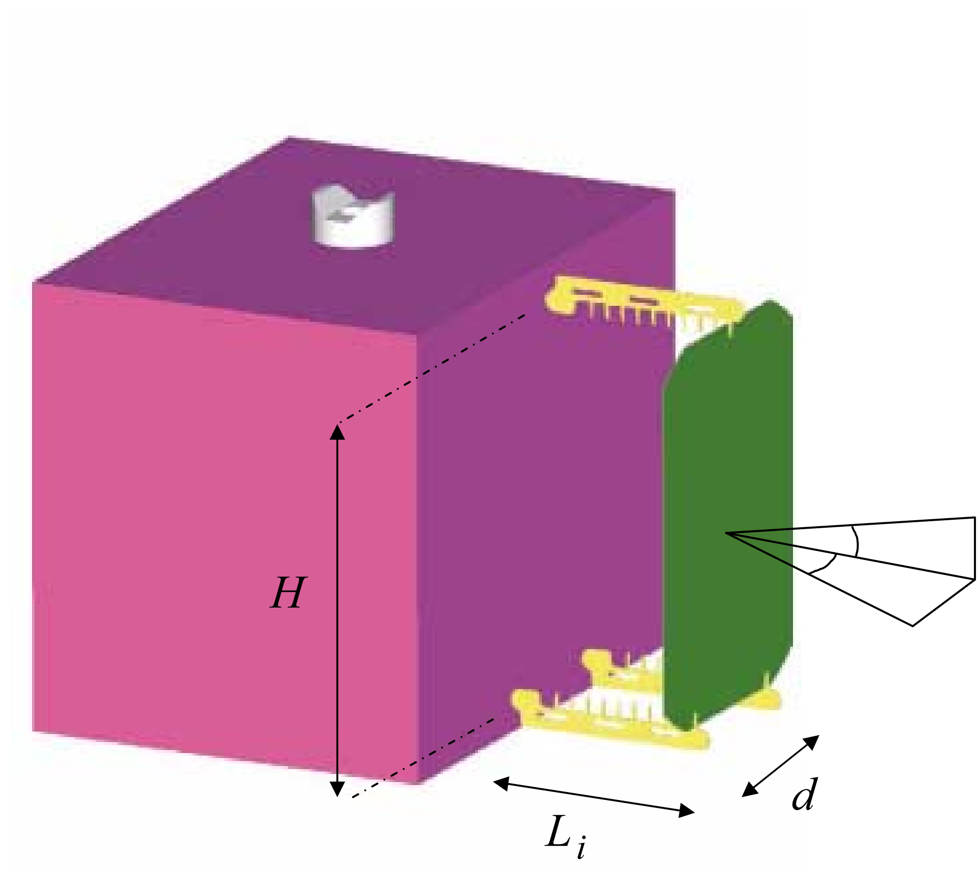
cj-fringlockoptics.eps

Modular Assembly



Assembly Truss and Alignment of Foil Optic to Reference Surface



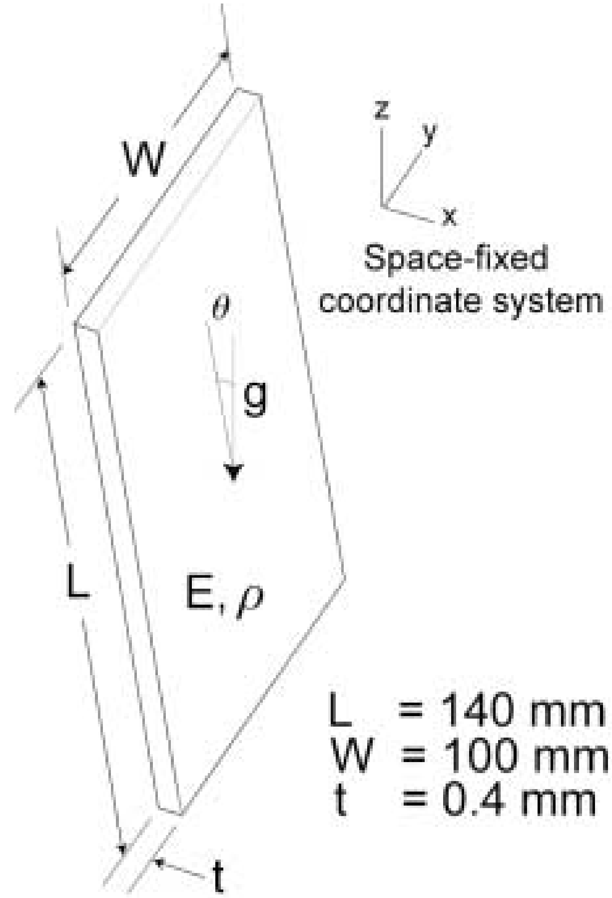


Foil Optic Deformation

- Gravity sag

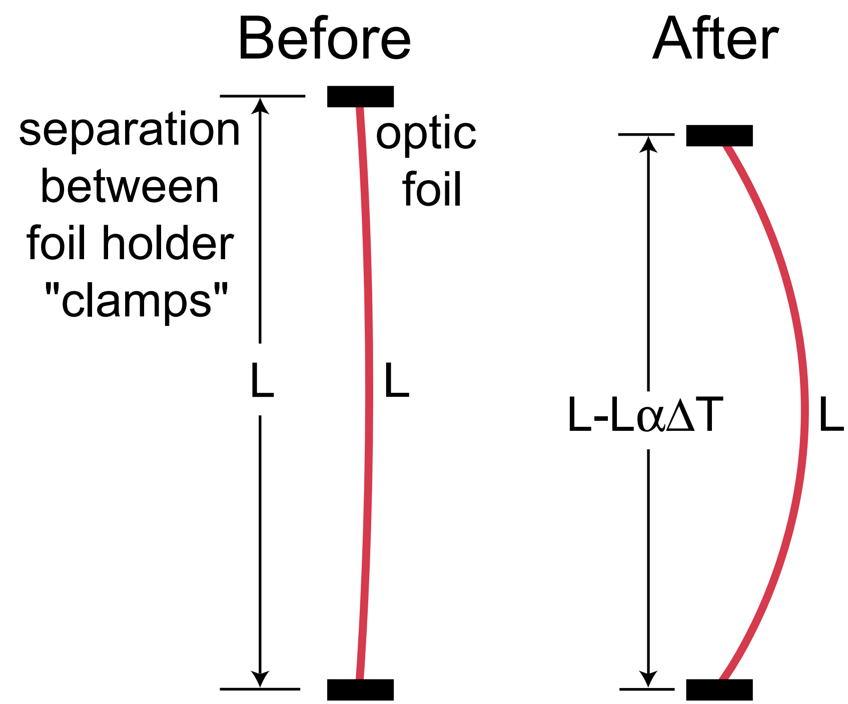
- Thermal expansion mismatch between foil and constraint

- Friction from physical manipulation (assembly, etc.)

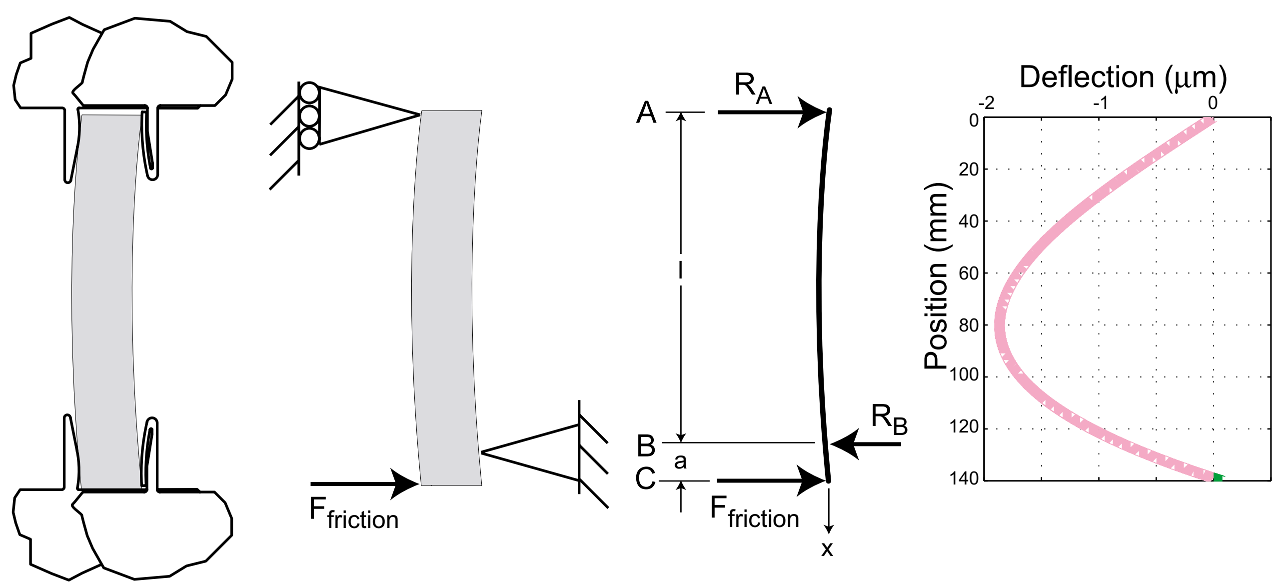


Foil Deformation Examples

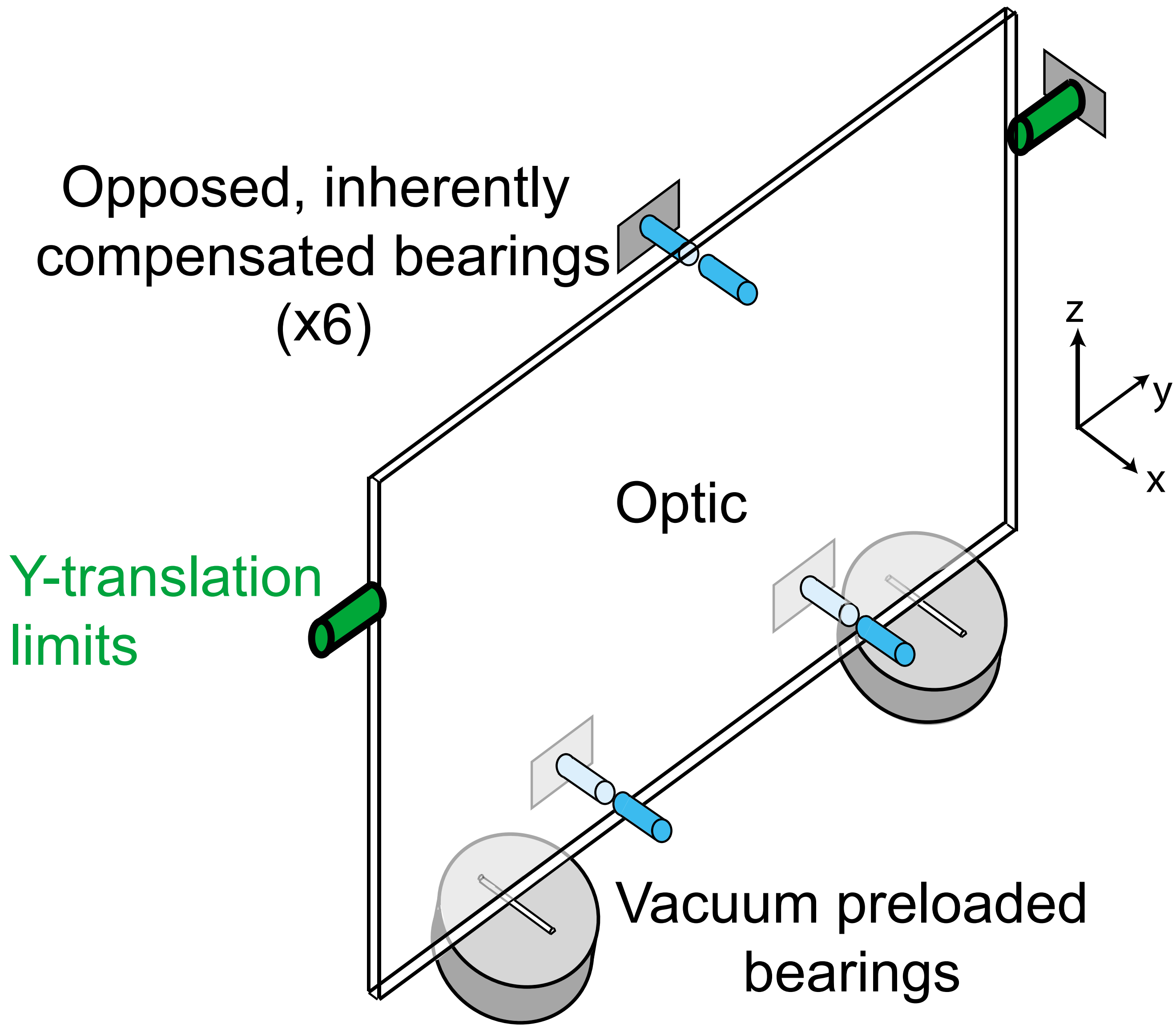
Thermal expansion mismatch



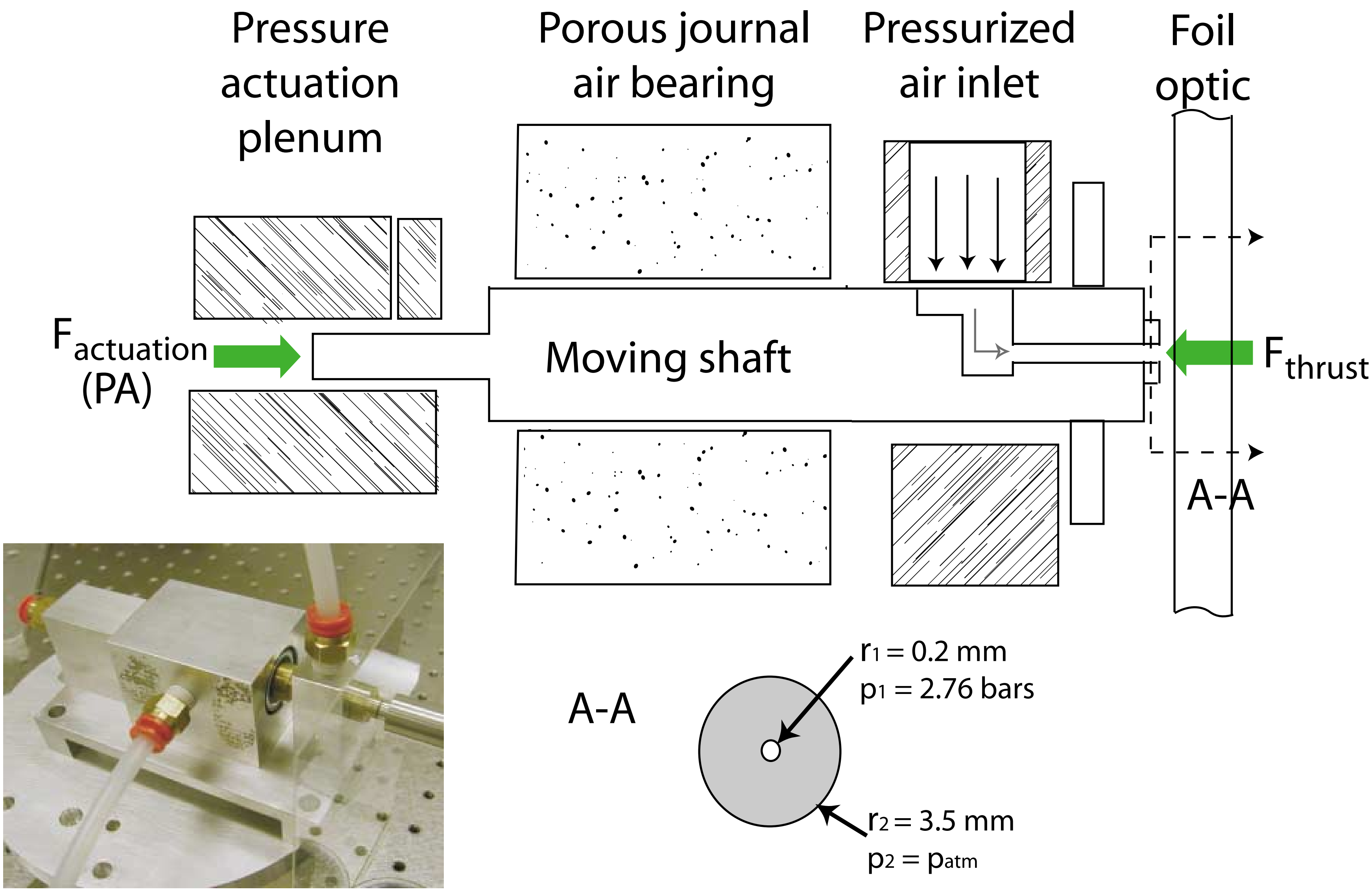
Friction



Holding foil optics for metrology

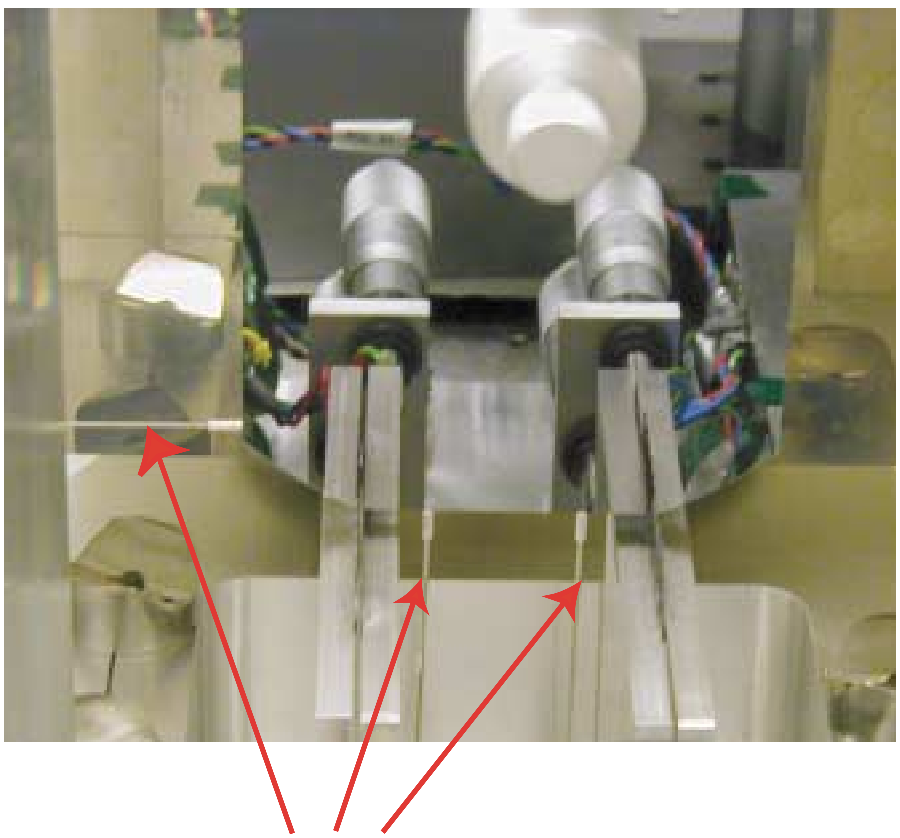


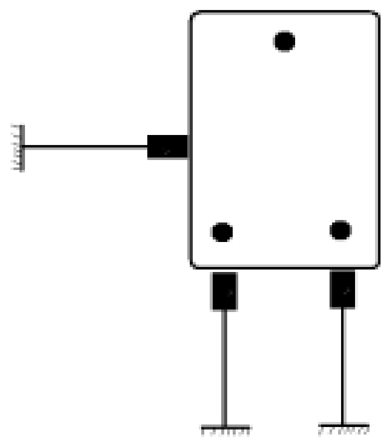
Air bearing design overview

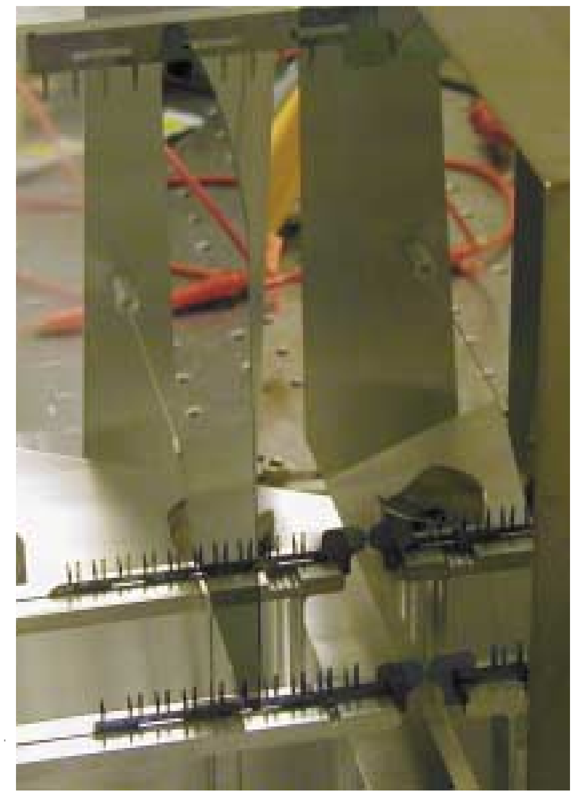


Flexures improve placement repeatability

Replace optics: repeatability ~ 10 - 20 nm!
Fully "dynamic" test (no side flexure): 60 nm (pitch); 0.6 ∝m (yaw)
Overall angular accuracy: 1-2 ∝m (reference surface flatness ~ 1.5 ∝m)







Summary:

- Fabricated efficient reflection gratings for in-plane and off-plane geometries
- Studying high-fidelity, low stress replication technologies (large-area Nanoimprint Lithography)
- Completed preliminary design of variable-period patterning system (chirped/radial gratings)
- Developing low-distortion foil optic metrology and alignment technologies